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INITIAL OPERATION AND CURRENT STATUS OF THE FERMILAB DZERO VMEBUS-BASED HARDWARE CONTROL AND MONITOR SYSTEM

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DZero is a large colliding beams detector at Fermilab. The control system for this detector includes twenty-five VMEbus-based 68020 computers interconnected using the IEEE-802.5 Token Ring local area network. In operation, the system will monitor about fifteen thousand analog channels and several thousand digital status bits, interfaced to the 68020 computers by the MIL-1553 multiplexed data bus. In addition, the VMEbus control system uses a memory-mapped multi-VMEbus interconnect to download parameters to more than one hundred VMEbus data crates in the experiment. Remote host computers can then read and set memory in the detector crates over the network by accessing memory in the control crates. This is an extremely useful feature during the construction phase, because low level diagnostics and testing of all the detector electronics can be done over the Token Ring network using either IBM-PC compatible computers or the laboratory-wide VAX system. The VMEbus control system hardware is now being installed in the DZero moveable counting house. Installation is expected to be complete later this year.

1. Introduction

Fermilab is constructing a large colliding beams detector for use at the DZero straight section of the Tevatron. This paper describes the VMEbus-based hardware control and monitoring system for the DZero detector with particular emphasis on recent changes that have occurred and the use of this system during the construction and installation period. An earlier description of this system is given in [1].

2. Overview

The DZero detector includes over 100,000 electronic channels with equipment housed in 72 relay racks on the detector platform and 75 relay racks in a three story moveable counting house. The complexity of detectors of this size requires a control and monitoring system similar to those used for a medium sized particle accelerator.

Figure 1 is a diagram of the DZero detector showing the interconnection of the control system and the detector electronics. For this detector these two systems are separate. A group of eight *unidirectional* 32-bit Data Cables transport digitized detector information to the VAX computers for processing. The unidirectional feature simplifies the design of the fast data acquisition, but it requires another path to the digitizer electronics for downloading pedestal information and operating parameters. For the DZero detector, the second path is provided by the control system.

Both the control system and the digitizer electronics use VMEbus. Although the VMEbus standard specifies 3U and 6U crates, the economics of building large quantities of identical circuits favors the use of large format cards. Detector electronics are built on 9U x 280 mm and 9U x 400 mm cards. The control system crates are 6U x 160 mm. Except for the minor annoyance of providing card extenders for use with standard 6U x 160 mm cards, the oversized card size has not been a problem. The selection of VMEbus, as a well-documented digital standard to follow, has been a major benefit—it allows the use of commercial VMEbus cards and unambiguously defines the backplane interface for all the custom cards designed for DZero.

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3. Architecture

The DZero control system includes a distributed group of 68020 based Local Stations housed in VMEbus and networked together using IEEE-802.5 Token Ring. This part of the DZero project, known as the hardware control and monitoring system, is the subject of the present paper. (See the unshaded portion of Figure 1.) Some data sources within the project, such as gas systems, the argon refrigerator and the first level trigger, are interfaced through IBM-compatible or VAX computers. These systems are not treated here.

There are three areas in the DZero facility: the detector itself and the platform that supports it, the moveable counting house, and the fixed counting house. The platform houses the analog processing electronics. The moveable counting house contains the digitizers, the first level trigger electronics, and the control system Local Station computers. Host computers and the microVAX farm that forms the second level trigger are located in the fixed counting house.

Analog and digital monitor data are connected to the Local Stations using the MIL-1553B multiplexed data bus. This standard was chosen to minimize cabling required for monitor signals and also to reduce the amount of digital noise on the platform. The MIL-1553 data bus is a transformer-coupled shielded twisted pair cable that has no continuously running clock, a feature that makes the cable dormant except when data is actively being transferred.

4. Hardware

Since the previous description of the system [1], several changes have occurred. Local Stations have been expanded to accommodate more analog and digital channels, the CPU card was changed from a 68000 card to a 68020, a serial Vertical Interconnect replaced the original parallel version, and geographic hardware identification registers have been added.

4.1. Local Stations

Each Local Station is a stand-alone microprocessor-based system that includes a VMEbus crate, a CPU card, non-volatile memory, interface to the network, a local database for the equipment it controls, support for a small local console, and I/O cards as needed to connect to the controlled equipment.

There are about 25 Local Stations in the DZero control system: 6 for reading the 200 Muon detector monitor boards, 6 for monitoring the 72 racks of equipment on the platform, 4 for monitoring racks and downloading parameters to digital crates on the second and third floors of the counting house, 6 for downloading to the high voltage system on the first floor and a few miscellaneous systems that perform tasks like reading cryostat temperatures and monitoring argon purity.

Local Stations repetitively read analog values from the equipment at a 15 Hz rate and make the results available to any requestor over the network. Repetitive and one-shot requests for data are supported. Because each station has a local database containing the names, calibration factors and the nominal and tolerance values of its parameters, it can scan the data it reads to check for analog or digital alarm conditions. Alarms are reported on the network and can be processed by any other computer on the network. It is expected that portions of the local database will be downloaded to the Local Station from the master hardware database maintained in the Host computers.

4.2. *Data Acquisition*

Monitor data is read into the Local Stations using the MIL-1553B multiplexed data bus. A VMEbus dual 1553 controller connects the Local Station to the data acquisition hardware. For interfacing to equipment in a single relay rack, a Rack Monitor chassis was designed as a 1553 Remote terminal. This chassis includes 64 A/D input channels, 4 words of digital I/O and 8 D/A output channels. This self-powered, 1U chassis is placed in nearly every relay rack in the counting house and on the platform. Local Stations read eight Rack Monitors on each of the two 1553 controller channels for a total of 1024 analog input channels per Local Station.

Each of the 200 Muon chambers includes a custom monitor board that is similar to a Rack Monitor. The Muon monitor board contains 32 analog input channels, 2 words of digital I/O and 4 D/A output channels. Each of six Local Stations reads a maximum of 12 Muon monitor boards on each of the four cables driven by two MIL-1553B controller cards.

Including both the Rack Monitors and the Muon system, the installed capacity of 16,000 channels of analog data and 2000 bytes of digital data can be collected by the Local Stations in about 18 ms.

4.3. *Vertical Interconnect*

The Token Ring-Local Station data path is used for downloading parameters to the detector digital data crates. A serial Vertical Interconnect was developed to map 16 MByte blocks of control crate memory into each of four digital data crates as shown in Figure 2. The upper byte of the 32-bit Local Station address selects the slave crate and the lower three bytes form the address for the memory access cycle in the slave crate. In the Local Station, these transfers simply appear as slow memory cycles, so there is no setup or resource reservation required. Access to the bus in both crates is gained through the normal VMEbus arbitration. Byte, word, long word, standard 24-bit addressing and 16-bit short I/O addressing transfers are transparently supported. The Vertical Interconnect uses AMD TAXI serial transmitters and receivers operating at a serial bit rate of 60 MHz. A long word transfer occurs in about 4 µs. As many as 24 slave crates are served from six Vertical Interconnect master cards in a single Local station.

4.4. *Network*

The control system network is a commercially available IEEE-802.5 Token Ring system operating at 4 Mbits/sec. Because the alarms checking is performed by the Local Stations, only the monitor data requested by consoles or other nodes will appear on the network. This traffic is expected to be small. Although there are several hundred kbytes of data to download, this data is normally sent at the beginning of each run.

4.5. *High Voltage*

A VMEbus-based high voltage system is under development for DZero. Each high voltage crate contains six 8-channel cards along with a CPU card that reads and controls the supplies. One Local Station is dedicated to each of six racks of high voltage equipment. Parameters for the high voltage supplies are read and set using the Vertical Interconnect.

4.6. *Geographic Identification*

In a very large repetitive system a single wiring error could cause one group of electronics to inadvertently receive data intended for a different group. For example, if two Vertical Interconnect cables were switched, the pedestals for one crate would be sent to another crate. To help avoid such problems, we are including a register on most of the equipment that can be read along with the normal monitor data. For the Rack and Muon monitors, an ID register is included as a separate MIL-1553B subaddress. For identification of VMEbus digital crates, a small board was designed to plug into the rear of the P1 connector. This board has a single read-only register accessed in the short I/O space of the crate. Higher level software can read these ID registers to verify that they are located at the expected address.

5. Software

The Local Station software has been in use for 7 years in the Fermilab Linac. A more recent version supports the Loma Linda medical accelerator controls. Since the previous paper on the plans for the system's adaptation for DZero [1], some significant changes have been made. A decision to upgrade from using an 8 MHz 68000 cpu to a 20 MHz 68020 cpu was justified on the basis that fewer Local Stations are required, as each can handle more channels. The addition of the pSOS multitasking operating system kernel provides the system with standardized support for task scheduling, memory allocation, event handling and message queuing, without loss of execution efficiency.

5.1. Cyclic Activities

The system software runs many of its tasks cyclically. Each 15 Hz cycle, synchronized with an interrupt signal, the Update Task reads the raw data into a datapool of analog and binary readings, and it fulfills repetitive data requests from the network and returns the answer response to the requester. The Alarm Task scans all analog and binary data for alarm conditions, encoding any resulting alarm messages for delivery to the network. The Console Task checks and updates local console hardware in response to keyboard, knob or pushbutton activity. The current application page program runs, using the fresh data from the datapool and/or that received from other nodes. Later in the cycle, the Server Task fulfills data server requests and returns the answers to the requester.

5.2. Asynchronous Activities

The Network Task processes messages that have been received from the network. The Serial Task processes lines of serial input received under interrupt control at rates of up to 19200 baud to handle real-time clock time-of-day messages or to save for use in satisfying data requests for serial data.

5.3. On-Demand Applications

A recent addition to the system software is support for on-demand applications. A Host computer can send a message that results in a selected application being invoked on a Local Station, whether or not a local console is attached. The Host program prepares parameters for use by the application and monitors its progress, presenting diagnostic information to the user at the Host display terminal and collecting the result data. This feature is used to measure liquid argon temperatures and argon purity in the DZero detector, where many local 1553 hardware accesses are required to gather the raw data needed to compute these values, and the measurement must be done only occasionally and at times which do not interrupt physics data-taking. Details of the implementation written to support this feature from a VAX are available in [2].

5.4. Functional Group Addressing

To make alarm messages available to multiple nodes, group functional addressing is used on the Token Ring network to provide a "multicast" form of addressing. In this way, the messages only have to be transmitted once, independent of the number of nodes that receive them. This same scheme may be used for data server requests.

5.5. Network Layer

The network layer supports general task-to-task communication across the network using a message header designed for use in Fermilab accelerator controls [3]. It will be used to support the network message protocol that has been designed for general use within DZero.

5.6. Data Server

The data server support allows a Host to make a data request containing references to multiple nodes and send it to one of the nodes. That node uses the network to request answer fragments from the various contributing nodes, collect these fragments and rearrange them for delivery to the original requesting node. This can simplify data request handling by the Host.

5.7. Remote CRT Image

Many Local Stations in DZero will not have an actual physical local console. Although most application pages provide equal access to the data from any Local Stations, the CRT Image application page can be used to access a station remotely and invoke applications that need to be run locally such as the 1553 Test Page.

5.8. Data Access Table Customization

Identical software is used in each Local Station. The customization of each station comes via information stored in nonvolatile system tables. Chief among these tables is the Data Access Table, which prescribes how and under what conditions the datapool is to be filled for each 15 Hz cycle. Nearly all of the controls data collected is read from 1553 hardware, most of which is accessed in blocks of 32 words from Rack Monitors. Multiple controllers using "message complete" interrupts allow overlapped 1553 data collection. As a result, using two controllers, 1024 channels of 1553 analog data can be read in 18 ms. Without overlap, it takes 35 ms.

6. Use in System Level Testing

The control system is expected to be essential for detector commissioning. The digitized data is buffered locally on each ADC board and transferred to a buffer in the Data Cable driver card in the local crate as soon as all digitizers in that crate are completed. During normal operation the buffer in the Data Cable driver would be switched from the input (VME) side to the output (data cable) side as soon as the transfer across the crate backplane was finished and the data sent to the level 2 processors. A diagnostic mode inhibits this transfer so that all the data from the cards and the buffer can be read out by any VME master in the crate. This can be a local personal computer or the control system. There is additional hardware which allows the trigger system to be bypassed so that a crate can be run in nearly a standalone mode thus allowing nearly complete debugging of each crate independent of nearly all the normal data acquisition system and much of the control system. All that is required is either a local computer or the operation of the token ring between the test computer and the crate. This has already been used extensively for test program development and checking. Much of the work is now done from the programmer's office rather than driving to the experiment. In the future, we hope that hardware problems will also be diagnosed by experts from their office. Ref. [4] describes the diagnostic system in more detail.

7. Current Status

Most of the Local Stations are now installed and operating in the moveable counting house. A few Vertical Interconnects are being used for testing the flash ADC and calorimeter systems. Cables for the 1553 connection to the platform and Muon systems have only recently been delivered, but some Rack Monitors and Muon chambers are being operated using temporary cables.

The schedule calls for full scale cosmic ray testing of all detector systems except the end calorimeters during the summer of 1990, and the first beam test is expected in May, 1991.

Acknowledgements

The system described here is the result of the combined efforts of many people. In particular, David Kewley and Jerry Blazey implemented the on-demand application page that measures liquid argon temperatures and purity. Al Frank and Rich Mahler are responsible for the Rack Monitor and the Muon monitor modules. Jim Engelbrecht fabricated the local consoles. Many colleagues and DZero collaborators have contributed to the design and implementation of various parts of the monitor system.

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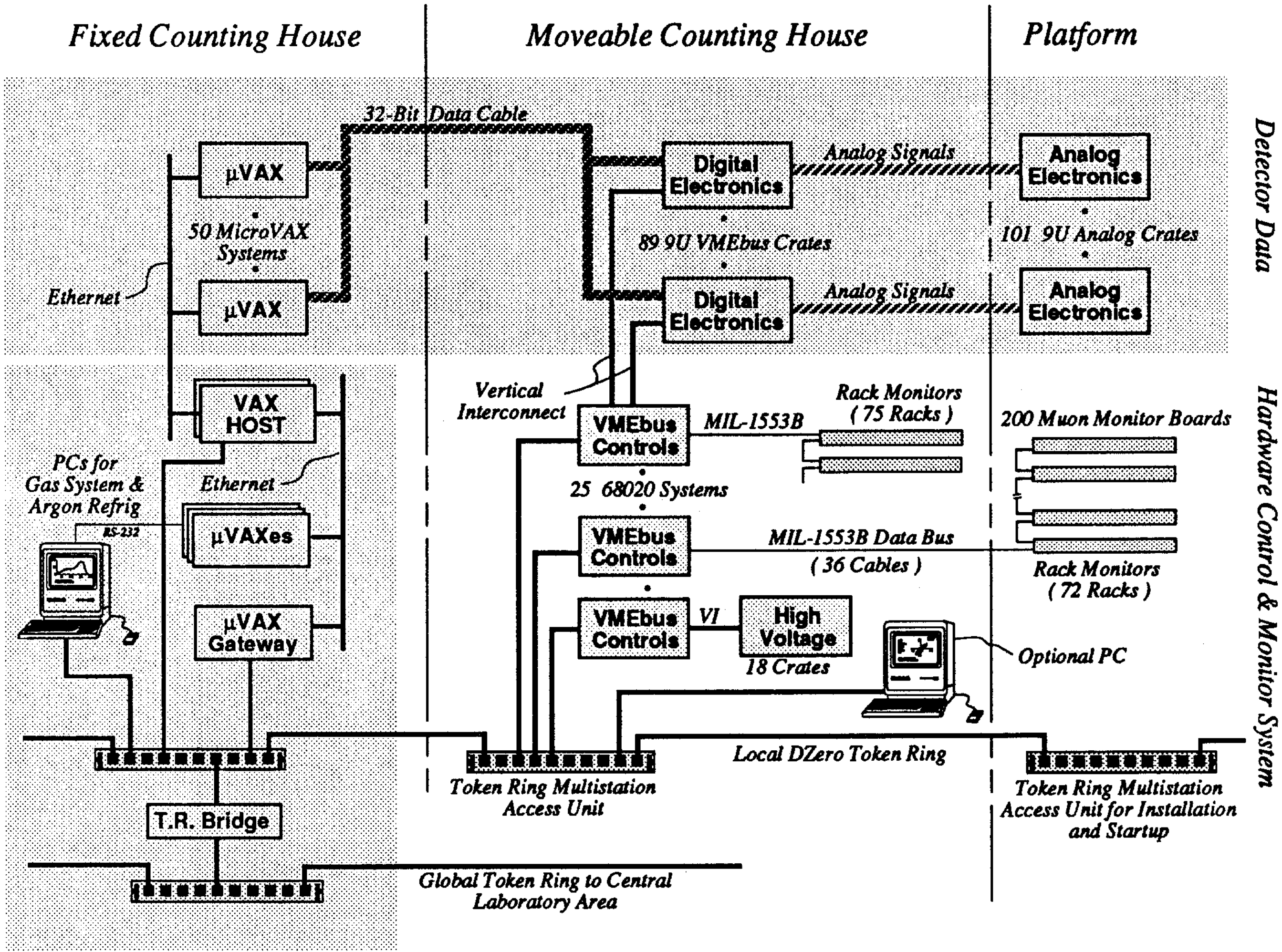

Figure 1. System Architecture for the DZero Detector

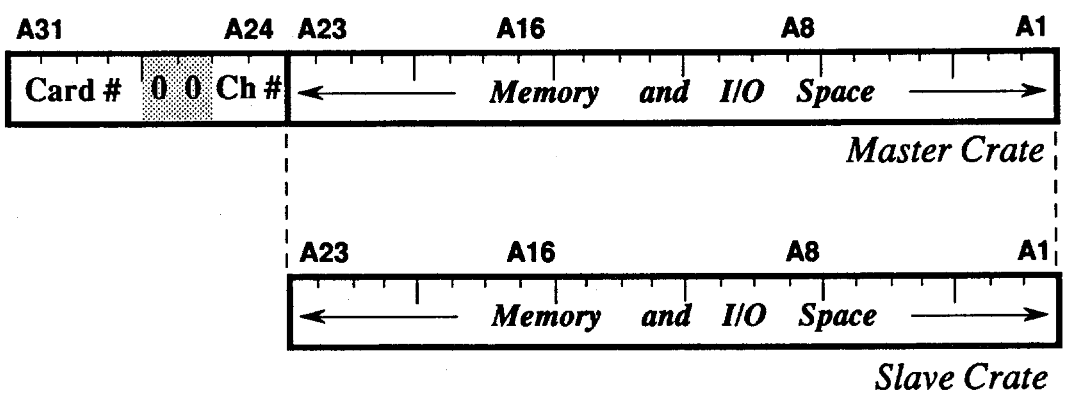

Figure 2. Memory Space of Vertical Interconnect Crates